AC 2011-1261: A HEURISTIC TO AID TEACHING, LEARNING, AND PROBLEM-SOLVING FOR MECHANICS OF MATERIALS

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A Heuristic to Aid Teaching, Learning and Problem-Solving for Mechanics of Materials

Abstract

A concept map heuristic is offered as a tool for teaching and learning in Mechanics of Materials courses. In this paper, we present a literature review wherein we list previous efforts to improve Mechanics of Materials learning and the use of concept maps for teaching. We provide our "common concept map," we detail several ways in which we've used the heuristic, and finally describe preliminary results assessing its efficacy.

Index Terms – Concept Map, Heuristic, Mechanics of Materials, Mind Map, Solid Mechanics, Strength of Materials, Undergraduate Mechanics.

Introduction

Mechanics of Materials is widely considered "difficult" by students. Many educators over the past two decades have attempted to improve Mechanics of Materials learning through endeavors such as the following: (a) development of physical demonstration models or video for classroom use,[1-2] (b) development of computer programs to assist, encourage and facilitate independent learning by students,[3-7] (c) concept inventory research to uncover the underlying cause of learning difficulty with the content,[8] (d) development of active learning strategies for use in the classroom, (e) project-based tasks for students to learn by doing, (f) peer teaching/learning and a (g) development of a more clearly articulated problem-solving approach has been proposed specifically for Mechanics of Materials to improve student learning[9].

Among our personal efforts to improve learning of Mechanics of Materials, we observed that students often miss the global connections of the many topics in the course, that students get "lost" in the midst of problem solutions, and that students have difficulty storing their knowledge in their memories. All too often, we have known bright students who were unsuccessful in recalling basic problems only a few weeks after completing the course. Through our multi-year and ongoing efforts, our goal is to help students make the concept and problem-solving connections using somewhat basic sketches they can recreate from memory simply using paper and pencil. In this paper we describe a basic concept map we have developed to use as an instructional aide which organizes the problem-solving process while showing the "big picture" components of the whole course. Our work began by having students develop their personal concept maps as a means to learn or to demonstrate their understanding of the course content. Those student-developed concept maps were not useful as instructional aides for a variety of reasons. First, the personal concept maps were so personal that the instructor had to interview virtually every student to uncover the intended meaning. Second, the personal maps showed so little commonality that they did not facilitate communication among students. Most importantly, student concept maps did not show the global connection of all topics taught in the course; neither did they aid in the problem-solving process, which was a primary goal of ours. Therefore, we created a "common" concept map which we use to teach and review Mechanics of Materials. This map has become a focal point for class lecture and tutoring. It is sufficiently simple so that anyone could re-create its basics as a hand-drawn sketch.

Concept maps have been used to introduce new subjects, to help students see the "big picture,"[10] to communicate the structure of curriculum between courses and within a course,[11-12] to assess[13-16] and they have been interactively animated[17]. Concept map ideas have been united with Mind Map ideas[18] and employed as a heuristic for fatigue analysis in Machine Design[19] with positive results. These previous efforts provided the framework to begin a similar effort for the Mechanics of Materials course. This paper describes the development, use, and preliminary assessment of a concept map heuristic for the first Mechanics of Materials course.

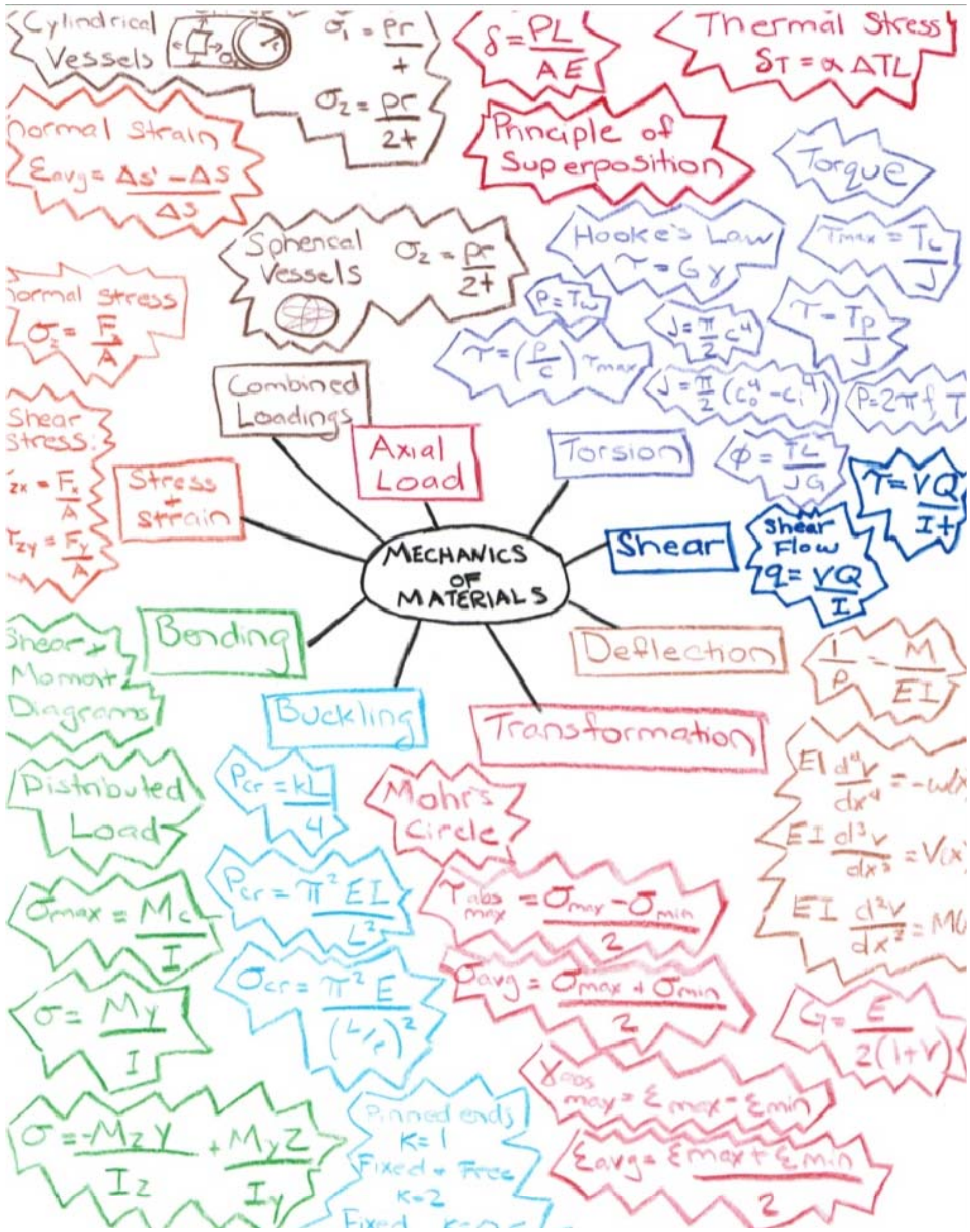

Figure 1. Example of student concept map with hub, without relational interconnections

Personal Concept Maps for Mechanics

Figure 1 shows a sample student concept map which is beautiful and engaging thanks to its color and dynamic appearance resulting from the pointed borders. It reveals a clearly-delineated "hub" but it also reveals the student's apparent lack of understanding with respect to how the spokes are related. The spokes appear as straight lines with no words or images to convey the relations among the colorfully-boxed titles.

It is revealing that the "Mohr's Circle" equations appear without any reference to principal stresses, their use, meaning, or calculation. Does the student think that the Mohr's Circle is *only* for transformation? Also, this map suggests (by color selection and placement) that pressure vessels *define* the condition of combined loading, as if they present the *only* combined loading to be considered. Finally, it is unclear why the concept called “Principle of Superposition” is included at the specific location shown. The student seems to think superposition is associated with axial and thermal deflection, implied by the like-color choice and proximity of those concepts.

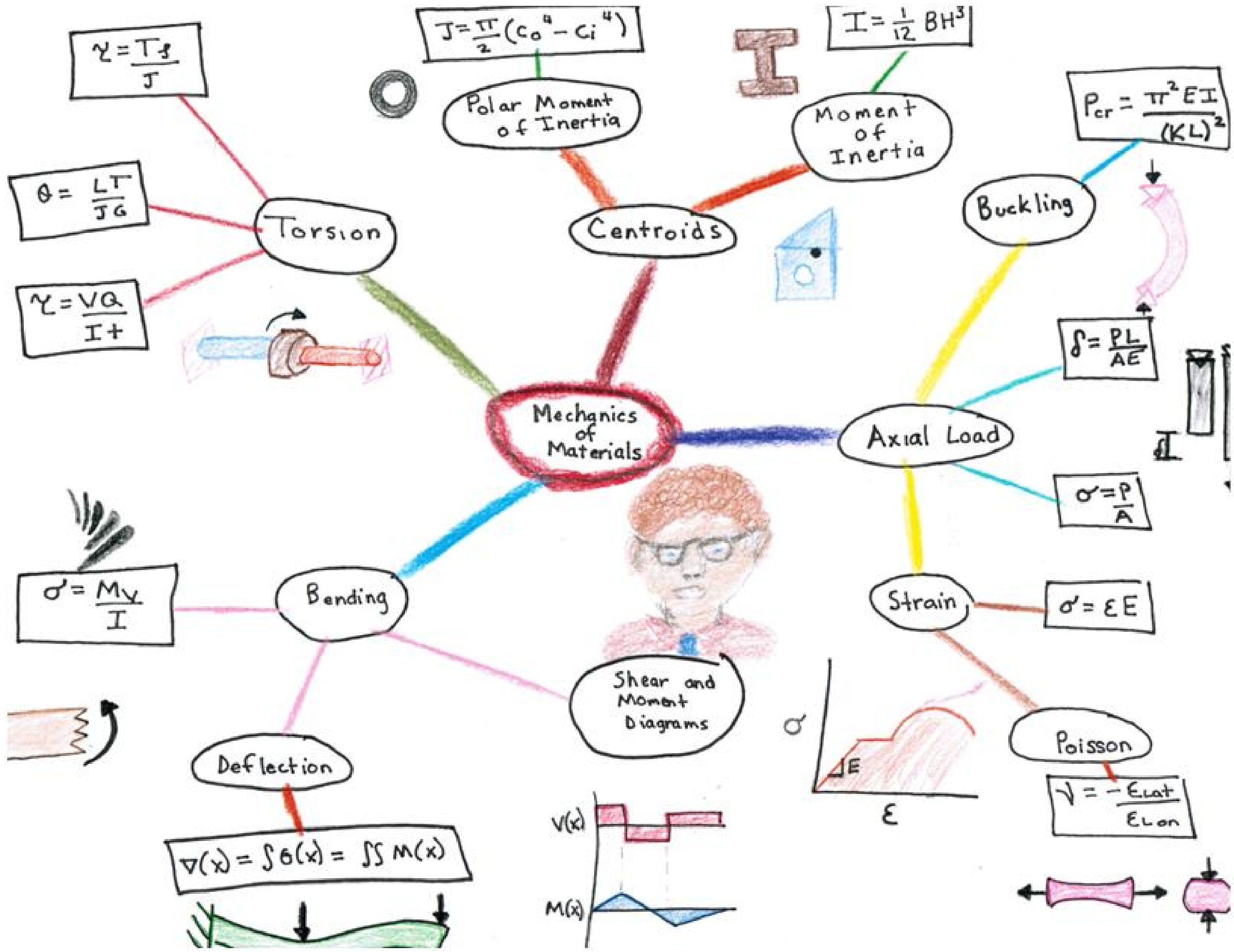

Figure 2. Example of student concept map using images to support words and equations.

Figure 2 shows another student’s concept map which is elegant in its simplicity. The inclusion of the self-portrait puts the student at the hub, and we educators agree that the student should persist in the center of our efforts as well. This map exploits simple stick-figures to augment the title words and the equations. However, this map neglects to include any reference to Mohr’s Circle, principal stress, and the symbol used for deflection, ∇, where the intention should be to use delta, Δ, reveals the student naiveté. The inclusion of color and images do help to make the words more memorable.

However, the Moment of Inertia image of the I-beam cross-section does not correlate to the equation offered, which is for a rectangular cross-section. Moreover, the transverse shear equation is grouped with the Torsion relations instead of with the Bending concept where it arguably belongs. The map lacks the idea of inter-related items.

The student map shown in Figure 3 makes an attempt to show the inter-related nature of the concepts, but also reveals this student's confusion as well. The map possessed dramatic color (as from highlighter felt pens) which was not captured in the image scanning process. The student uses words along the connecting spokes to convey additional meaning, and adds connections around the perimeter, an obvious indication that he understands things are interconnected. This student also omits several significant course ideas such as combined loading, principal stress and deflection altogether.

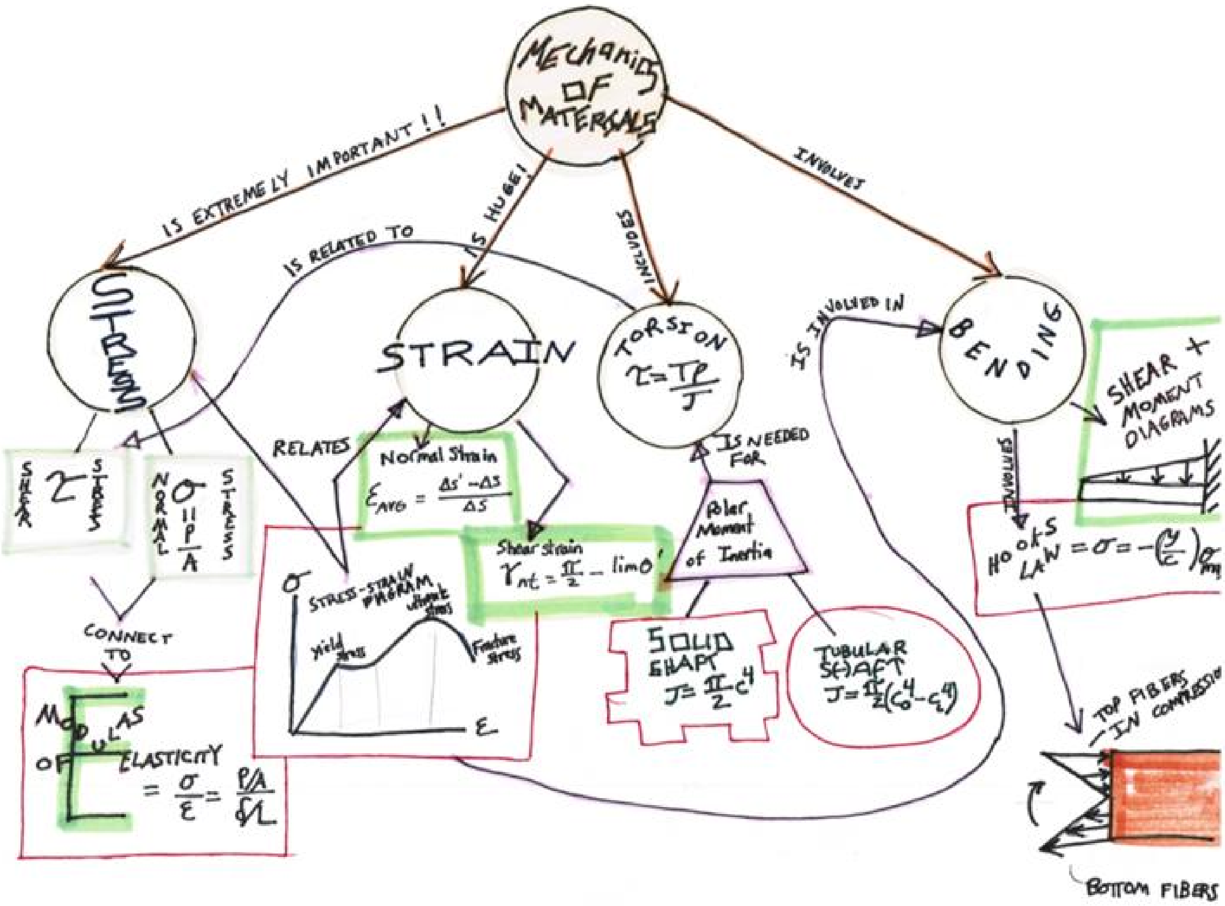

Figure 3. Example of student concept map using words, images and inter-relationships

Error-by-omission is the most common characteristic of concept maps we see from students. Our students seem to view the many topics as disjointed and unrelated, and they don't know how to solve real-world problems with the content we've conveyed in past Mechanics of Materials courses. These experiences with personal concept maps suggests that instructors need to more clearly articulate the overarching ideas and the interconnections as well as spell out the intended goals and applications of Mechanics of Materials.

Common Concept Map Heuristic

Our hypothesis with the creation of a heuristic is that a “common” concept map could be created and used to teach and to review topics in Mechanics of Materials. We wanted to create an image simple enough so that it could be re-created with only pencil and paper. We also wanted the image to convey relationships among the concepts and infer problem-solving processes.

Knowing that recalling items in groups is easier[20], we chose to use three basic “areas” in the heuristic, shown in Figure 4, labeled A, B, and C. The A-area is shown with a pointer toward the B area, implying “input” to B. We intentionally chose to highlight the overarching assumptions which apply to all of the Mechanics of Materials topics, and we have used this list to remind students frequently about the importance of assumptions and their impact on selection of points of interest. When we choose to violate the assumptions, we do so with full recognition that we know our calculations are appropriate for the (first order) level of analysis we are conducting. If we need greater detail, we know when to use a more refined tool than undergraduate mechanics analysis. Note that the central word, loading, does not appear in Figure 4, since it is the “hub” of the heuristic.

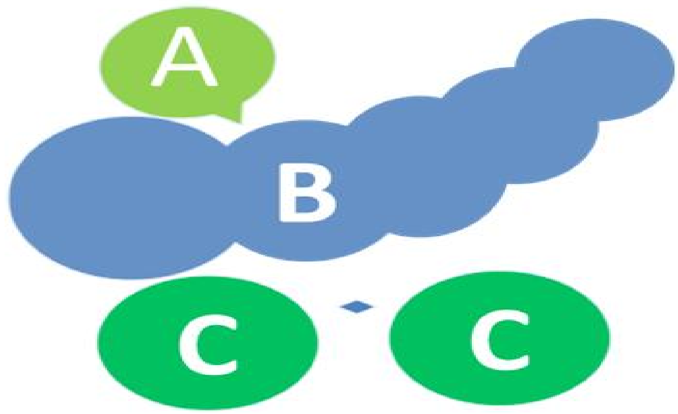

Figure 4. Three Map Areas Infer Problem Solution Path.

Turning our attention to area B, this collection of “bubbles” represents the basic loading types. The B areas all point or feed into a decision diamond. This diamond symbol was chosen intentionally to represent a decision point, where the analyst combines calculation results from area B and proceeds to one of two general design criteria areas in C. The notion of three basic areas, A-B-C, helps aggregate many of the details in a visual way which research has shown to assist with memory[20].

Turning to the full heuristic, Figure 5, we have intentionally chosen to use characteristics of both concept maps and mind maps because the images are powerful memory enhancers for most engineering students. The B-area bubbles are filled, each with key equations and some with figures intended as a quick reminder of the load application. The C-area bubbles are also filled with cues to design criteria, namely stress analysis using Mohr’s Circles or deflection analysis using one of several techniques listed. Most mechanics-style analysis of “real” components ends up with a decision based on stress or deformation as the common design/analysis criteria. With large safety factors, perhaps only the stress calculation will be the defining factor, so stress could be the only or the final criterion for the analysis. However, many components require stress and deflection to be considered in the design or analysis, so the diamond shape is a sign to think about both. The diamond decision connector is also an indicator that all stresses (from the many possible loadings) “collect” together to be applied in the evaluation phase using the Mohr’s Circle and in calculating the principal stresses.

The deflection bubble is intentionally simplified, with just the list (a memory cue) of methods learned to determine deflection (and slope) accompanied by the abbreviated discontinuity function table. Through additional investigations in the upper-level Machine Design course, we have determined that the discontinuity function approach is the most direct for complex geometry (variable cross-section as with stepped or tapered shafts) subjected to variable and/or repeated loads in possibly multiple planes[21-22]. The table and equations may not be absolutely clear here, but they remind the user to use the "real" table and to begin by writing the discontinuity function for the moment equation for the entire beam as the best way to approach the deflection solution for any point along the beam.

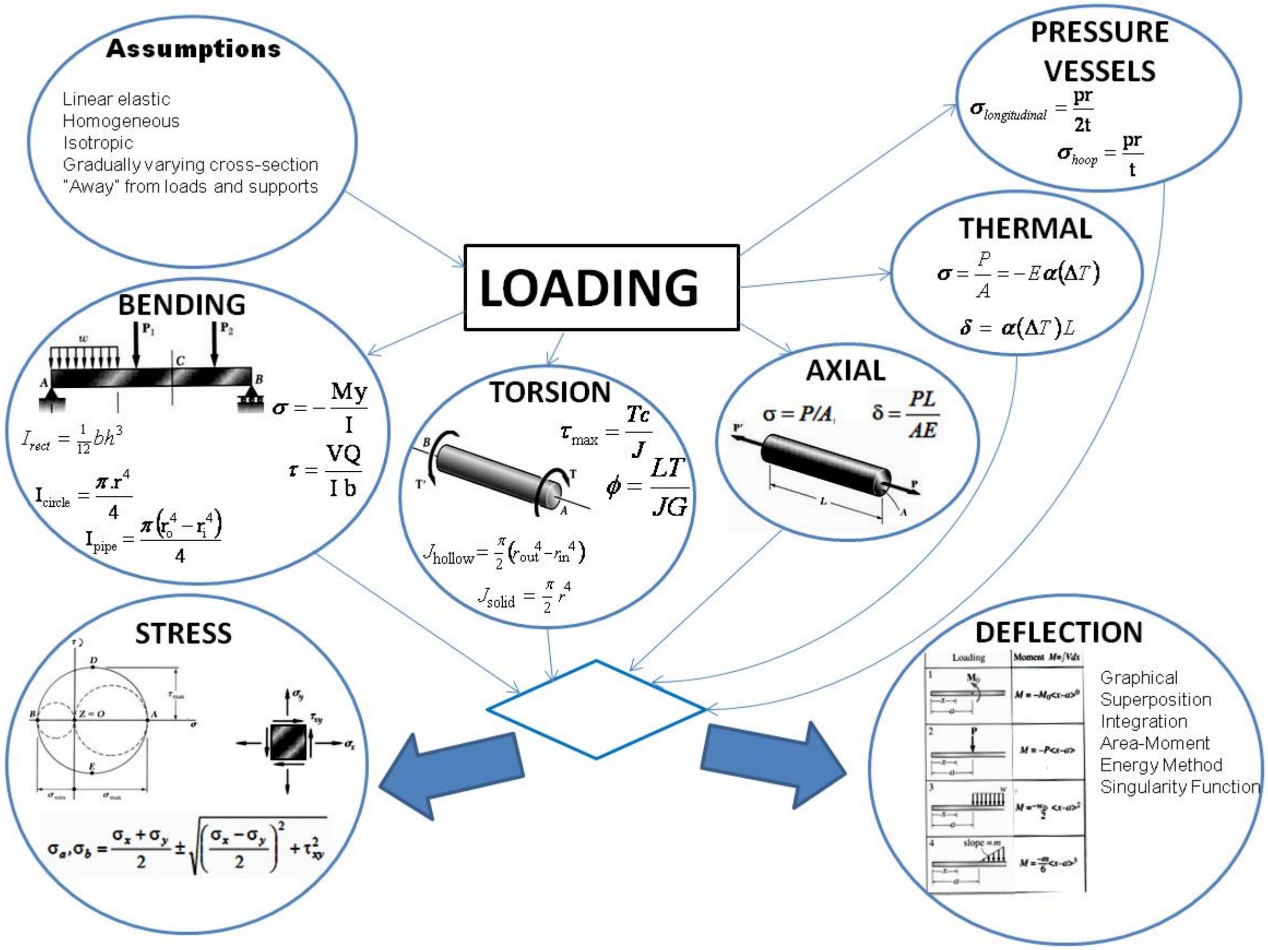

Figure 5. Instructor-Developed Common Concept/Mind Map for Mechanics of Materials

Uses of the Mechanics Heuristic

We have used portions of this heuristic informally over several years as the character of the tool developed. Like many instructors, we began with *lists* of equations and *lists of lists* which evolved into images inside of circles with arrows. Last year we printed and distributed the one-page map and used it as a review tool for two groups of students.

One review group included seniors preparing the Fundamentals of Engineering (FE) exam. Mechanics of Materials was reviewed in one, fifty-minute class using this heuristic as a handout and as a smart-board image which could be written on and annotated. The FE review course includes students from four engineering majors (Civil, Electrical, Mechanical and Marine), *not* all of whom had taken the Mechanics of Materials course. A second review group was the students in Mechanisms course.

Efficacy

The Mechanisms course involves Mechanical Engineering students at the junior level, three semesters after Mechanics of Materials. The gateway exam includes 16 problems from the Mechanics of Materials content. The Mechanisms gateway exam was the same for all years, so a comparison between the three year groups (shown in Figure 6) is informational. We see the significant improvement of performance on this gateway exam; we investigated other factors which might contribute to such a difference. We found such student characteristics as overall grade point average, grade average in Mechanics of Materials and entering SAT scores were not significantly different among the three groups. We are confident that the exercise of review coupled with the use of the heuristic are the reasons for the increased average score.

For the FE review course students, we obtained no change in student performance in the Mechanics of Materials portion of the FE exam in 2010. Using anecdotal assessment, based on observations and non-scientific polling of student opinions, the feedback has been bimodal: Some of the Electrical Engineering majors expressed frustration and confusion because the heuristic was too cryptic and complex for them, presumably because they were seeing this information for the first time. Students who completed the Mechanics of Materials course have offered positive comments, such as:

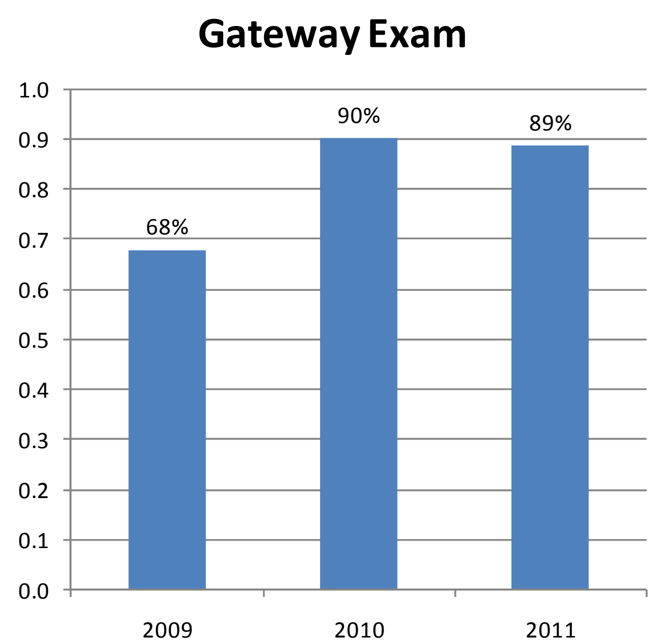

Figure 6 Comparison for Three Years of Gateway Exam Scores

> "…the map helped me tie that concept in to everything we had learned…"

> "…concept map helped to visually demonstrate how all the topics covered in class related to each other in the terms of mechanics of materials…"

> "I think it helped make the overarching principles make more sense…"

> "The concept map does make sense to me, but I had to go over to it to figure out what was linked to what… to show us how all of the things we learned were to connect to each other."

We offer one final comment regarding the value and use of this heuristic. We value the focus which this tool provides, as a point of discussion, learning and questioning. We have observed our students engage with us and with each other in analytical conversations which are richer, more thoughtful and reveal deeper understanding; we believe such conversations are a result of using this tool. Some students have suggested improvements, many of which we are giving serious consideration in attempts to continuously improve learning.

Conclusions

We investigated use of concept maps and other tools available for enhancement of instruction and learning centered around Mechanics of Materials. We hypothesized that students' difficulty has been exacerbated because they have trouble comprehending how the many topics are inter-related and they are unsure how to proceed with analysis. We created a common concept map using principles of mind maps, concept maps and heuristics. Although significant value has been captured using the heuristic as a review tool at the beginning of a follow-on course, no value is evident as a tool for FE exam review. Students' opinions of the heuristic's value have been mixed, with those who have completed a Mechanics of Materials course generally positive and those who have not generally negative. As faculty we have observed our students engaging in richer, more thoughtful discussion using this heuristic, and they have revealed in these conversations, a deeper understanding of the Mechanics of Materials content.

Acknowledgment

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